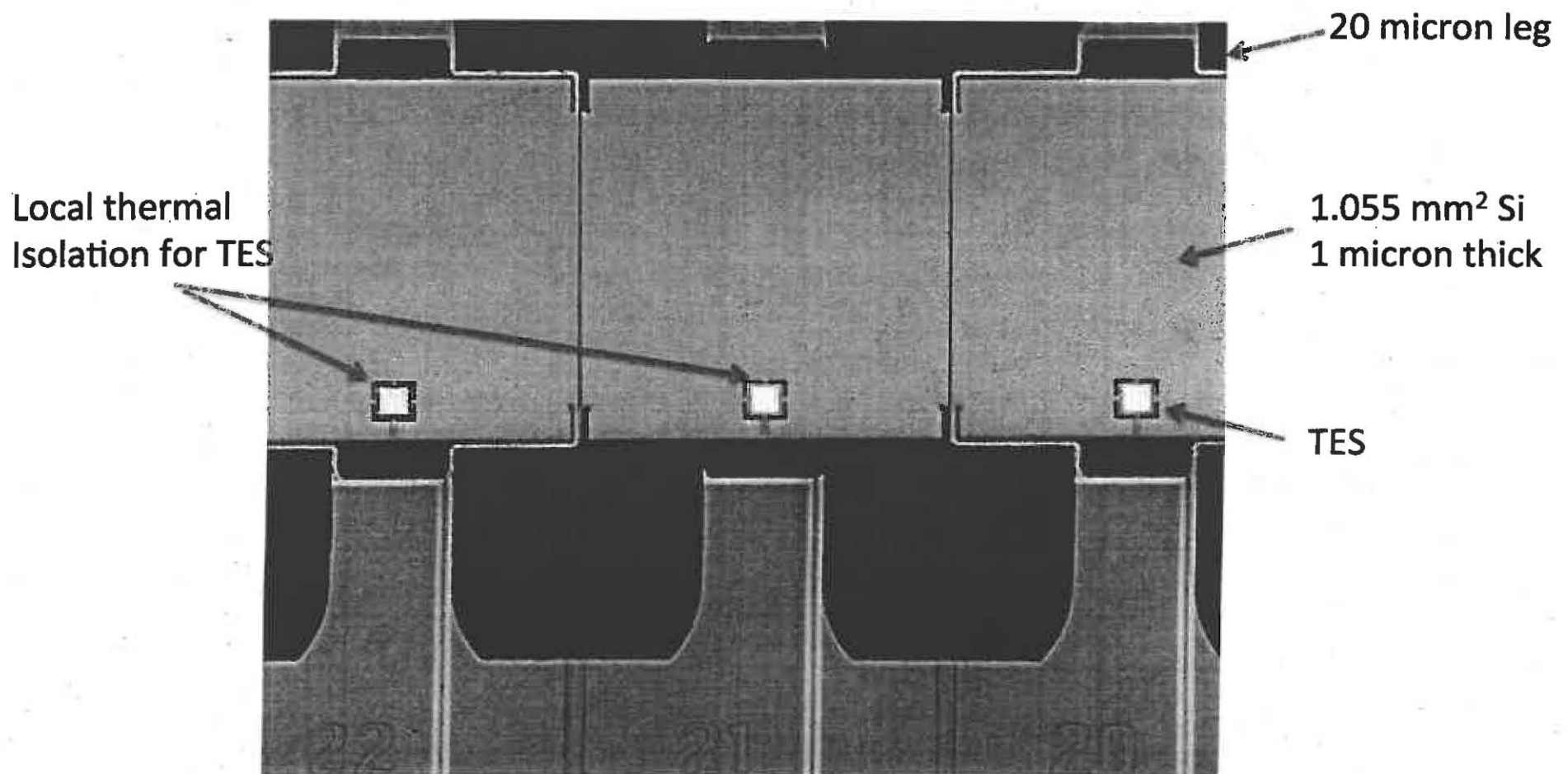


Phonon mechanisms for excess heat capacity in membrane isolated superconducting transition edge sensors

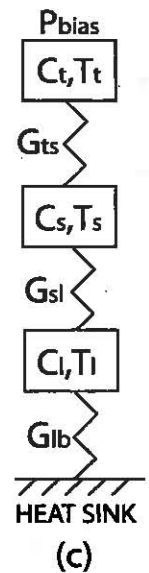
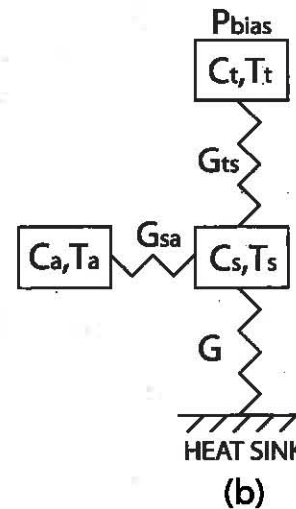
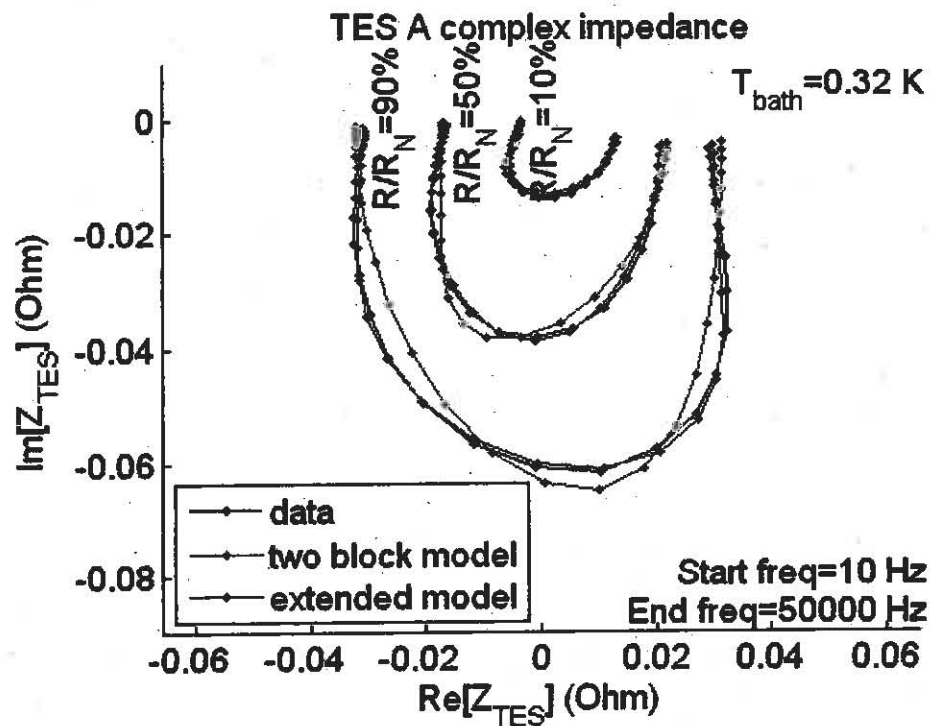
James A. Chervenak, NASA Goddard Space Flight Center

The mechanics of phonon transport in membrane-isolated superconducting transition edge sensors is discussed. Surveys of the literature on this type of sensor reveal a number of designs with excess heat capacity and a smaller subset that exhibit decoupling of the superconducting film from the underlying dielectric. A simple model is addressed in which the membrane, despite its thermal isolation, fails to fully thermalize to the temperature of the metal film heating it. A population of phonons exists which is emitted by the metal film, partially thermalizes the dielectric and is then reabsorbed in the metal film without escaping from the device structure to the thermal bath. The size of this population and its contribution to the heat capacity are estimated for several device scenarios.

Large membrane bolometers



Excess Heat Capacity Discussion

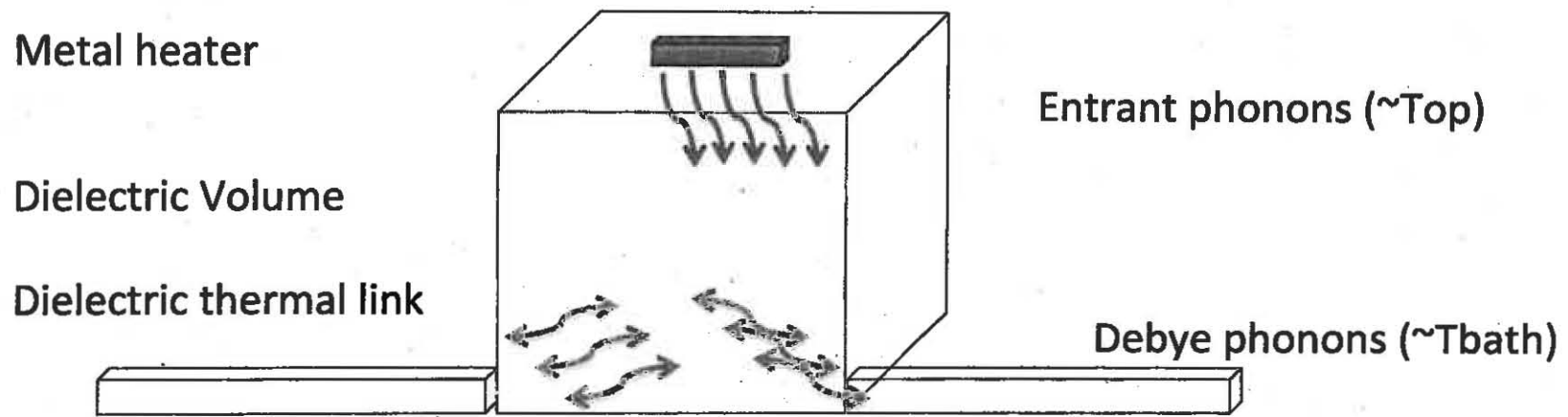


Empirical models for large membrane bolometers have added heat capacities to fit data such as complex impedance

Suspected causes of heat capacities

- Two level systems
- Dielectric surface roughness effects
- Contamination
- Bolometer design (such as leg width)

Membrane Isolated Transition Edge Sensor



Device conditions:

Membrane volume is large compared to metal volume on TES

Surface area of TES metal on membrane is such that phonons emanate from a small region into membrane volume

Assume phonon-phonon thermal transfer is weak or non-existent such that time constant for phonons to thermalize membrane becomes \sim , $>$, or \gg than device τ

Debye and Kapitza

Debye theory counts the phonons in the box and multiplies by the thermal distribution

So the question arises:

If the interactions are weak at low temperatures, can a system that pumps phonons into a box reach a non-thermal distribution? If so, do those phonons add to the heat capacity?

Kapitza formula is, in practice a reasonable approximation in metal:dielectric interfaces but does not give exact values

Various scattering phenomena have been calculated (Maris, Kosoresov)

If phonon reabsorption (emitted by metal, partially thermalized in silicon, and transferred back into the metal) can occur, what ratio of time constants (ph-ph in the silicon vs ph-ph silicon to TES metal) would need to exist to alter the internal time constant of the device

Phonon Blackbody Calculation

If the phonons are non-interacting, the added phonons will eventually fill the volume with a blackbody distribution proportional to the maxima of the phonon frequency spectrum emitted by the metal film at its operation temperature

We use K. Huang's formula for heat capacity of a blackbody distribution
Kosoresov description of phonon spectrum:

Count of phonons needed to thermalize dielectric

For the case where the phonon thermalization in the dielectric is finite:

To calculate the total phonons in the box during a detector time constant:

Estimate phonon emission per second from hot metal film

If membrane thermalization is faster than detector time constant, membrane will eventually approach metal film in temperature, excess heat capacity is Phonon count to maintain temperature

If membrane thermalization is slower than detector time constant, unthermalized phonon contribution is dependent on number of time constants.